# FIBER-OPTIC INTERFEROMETRIC ROTATION
# SPEED SENSOR DEVICE

5      CROSS - REFERENCE TO RELATED APPLICATIONS

The present Application is based on International Application No. PCT/EP2004/051904, filed on August 25, 2004, which in turn corresponds to FR 03/11317 filed on September 26, 2003, and priority is hereby claimed under 35 USC

10     §119 based on these applications. Each of these applications are hereby incorporated by reference in their entirety into the present application.

BACKGROUND OF THE INVENTION

15     Field of the Invention

The present invention relates to a fiber-optic interferometric rotation speed sensor device (or gyroscope).

20     Description of Related Art

The rotation speed sensor device to which the invention relates is based on the principle of the interference of two waves, in which one of the mirrors is a nonlinear optical component of the phase-conjugate mirror type. The gyroscope

25     system produced from this sensor relies on the following two properties of the interferometer, which were demonstrated for the first time in the following reference: Ph. Graindorge *et al.*, "Fused reciprocity using phase conjugation" in Fiber Optic Rotation Sensors – Springer Verlag, 1982.

These properties are the following:

30     - if a reciprocal phase shift $\delta\phi_r$ is introduced into the signal arm, it is not seen by the detector (+ $\phi_r$ - $\phi_r$ = 0);

- if a nonreciprocal phase shift $\varphi_{nr}$ is introduced into the signal arm, the phase variation of $2 \varphi_{nr}$ is measured after detection.

Consequently, the interferometer sees only the nonreciprocal phase shift effects – this is the case of the Sagnac effect, used to advantage for producing a

5 rotation speed sensor.

The conjugate wave is generated in the lasing medium itself. This is a solid-state monomode monofrequency source. Effective phase conjugation experiments have already been the subject of publications, in particular in Nd:YAG and Nd:YVO$_4$ lasers (see A. Brignon *et al.*, "Phase conjugation in a continuous wave diode pumped

10 Nd:YVO$_4$ laser" in Applied Physics B, 1999). To produce a gyroscope, the beam output by the laser is injected into a fiber loop (of diameter D and having N turns, which means that the length L of the fiber fiber is: $L = N \pi D$ ).

Gyroscopes based on a polarization-maintaining monomode optical fiber are known e.g. from French patent 2,516,232. Such an optical fiber is relatively difficult

15 to align optically with the optical devices that have to be coupled to it.


SUMMARY OF THE INVENTION

The subject of the present invention is a fiber-optic rotation speed sensor that can use a large-core optical fiber, which is easy to align optically with the devices

20 that are associated therewith.

The fiber-optic interferometric rotation speed sensor device of the invention comprises a laser source combined with an optical fiber and with a device for making the beam from the laser source interfere with the beam coming from the optical fiber, and it is characterized in that the laser source is an optical cavity having a gain lasing

25 medium and in that it includes, along the path of the beam output by the laser cavity, a beam splitter device associated with a reflecting device, the beam split off from the beam output by the laser cavity being sent into one of the ends of the optical fiber, the other end of which is directed toward the gain lasing medium that forms a nonlinear mirror, the splitter device being followed by a detector.

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BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be better understood on reading the detailed description of an embodiment, given by way of non-limiting example and illustrated by the appended drawing in which:

- figure 1 is a simplified diagram of an interferometric sensor according to the invention;

- figure 2 is a simplified diagram of a diffractive splitter that can be used in the sensor of the invention;

- figure 3 is a simplified diagram of an interferometric sensor according to the invention, incorporating the splitter of figure 2; and

- figure 4 is a partial diagram of an interferometric sensor according to the invention, using a non-polarization-maintaining optical fiber.

DETAILED DESCRIPTION OF THE INVENTION

The interferometric device shown schematically in figure 1 comprises a compact laser 1, which in the present case is a gain medium formed by an optical cavity 2 defined between two mirrors 3, 4 and pumped by a beam 5 emitted by pumping diodes 5A, a lasing medium 6 being placed in this cavity 2. This laser is monomode and monofrequency, operates in continuous mode and is polarized. Two counter-propagating beams 2a and 2b oscillate inside the cavity 2. Placed in the path of the output beam 2c of the laser 1 are a splitter plate 7 and, behind this plate, in the extension of the same path, a mirror 8, which is perpendicular to this path. The beam 2d, split off by the plate 7 from the beam 2c, is injected into one end of the uniformly coiled optical fiber 9 in the form of a flat coil. The other end of the fiber 9 is directed toward the center of the lasing medium 6 in order to intersect beams 2a and 2b therein. The beam 9a output by the fiber 9 in the direction of the gain medium 6 interferes with the beams 2a and 2b inside the medium 6, creating a dynamic hologram. The beams 2a and 2b, by diffracting on this hologram, generate a conjugate beam 2e which is sent into the fiber 9. On leaving the fiber 9, this beam 2e passes through the plate 7 and arrives on a photoelectric detector 10, on which also

arrives a beam 2c' that represents that part of the beam 2c reflected by the mirror 8 and by the plate 7 toward the detector 10. These two beams 2e and 2c' interfere with each other on the detector 10.

The assembly described above is equivalent to a Michelson interferometer, in
5    which one of the mirrors is a nonlinear mirror formed by the gain medium 6.

At the photodetector 10, if $\varphi$ is the phase shift between the two beams 2e and 2c', the expression for the intensity detected by the detector 10 is of the form: $I_D = I_0(1 + \cos\varphi)$. The position of the mirror 8 is chosen so as to satisfy the condition $\varphi = \pi/4$, which allows the interferometer to operate in its linear response
10    zone. Under these conditions, the signal $I_D$ output by the photodetector 10 is written as:

$$I_D = \frac{I_0}{2}\,\delta\varphi_{NR}$$

where $\delta\varphi_{NR}$ is the nonreciprocal phase shift due to the Sagnac effect in the N-turn fiber loop 9, and

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$$\delta\varphi_{NR} = \frac{4\pi LD}{\lambda_0 c_0}\,\Omega$$

where:

$\Omega$ = angular rotation speed of the coil of optical fiber 9;

D = diameter of the coil of optical fiber 9;

L = length of the optical fiber;

20    $\lambda_0$ = wavelength of the laser 1 *in vacuo*; and

$c_0$ = speed of light *in vacuo*.

Another embodiment of the device of the invention is shown in figures 2 and 3, figure 2 representing a detail of the assembly shown schematically in figure 3. The sensor device shown in figure 3 is similar to that of figure 1, with the main difference
25    that the beam splitter 7 is replaced with a diffraction grating operating both in reflection mode and in transmission mode. This sensor device essentially comprises a laser cavity 15, similar to the cavity 2, a flat coil of optical fiber 14 and a reflecting beam splitter device 13, shown in detail in figure 2.

More precisely, as indicated in figure 2, the beam L output by the laser cavity
30    15 is diffracted in the $\pm\,\theta$ direction, by reflection (beam R) and by transmission (beam D) respectively. This type of grating is for example produced in a manner

known per se by holographic techniques for writing into photopolymer materials (a photoinduced index grating or a relief grating). These two types of grating may also be multiplexed within the actual volume of photopolymer material. The reflected beam R is coupled into the coil of fiber 14 (figure 3) and then conjugated after

5    reflection on the nonlinear mirror that the lasing medium 16 constitutes (similar or identical to that of the cavity 2 in figure 1). The conjugate beam C is sent into the fiber 14 and interferes in the grating 13 with the beam L output by the source. The benefit of this diffractive component is that the condition $\varphi = \pi/4$ for interferometric detection can be easily satisfied. By interfering with the beam L, the conjugate beam

10   C creates a fringe structure, the period of which corresponds to the pitch of the transmission grating. Under these conditions, the beam C transmitted directly by the grating and the beam D output by the diffraction of L by the grating 13 interfere on the detector 17. It is known from the phenomenon of beam coupling by gratings that the phase shift between the two beams D and C is controlled by the position of the

15   grating relative to the interference fringes formed by interference between C and L. A quarter-period spatial shift of the grating while it is being written will ensure that the linear detection condition is met.

The rotation speed sensor based on a fiber interferometer according to the invention is compatible with the use of a multimode fiber. Insofar as a four-beam

20   mixing function is carried out in the cavity (namely with the beams L and L', which propagate in opposite directions in the cavity 15, and the beams R and C), the beam output by the fiber may be multimode: by phase conjugation, there is again a plane-wave beam C identical to that injected into the coil of optical fiber.

The operating principle of the device according to the invention is also

25   compatible with the use of a non-polarization-maintaining optical fiber. As mentioned in the reference: "Gain grating analysis of self-starting etc." by P. Sillard *et al.*, IEEE – J.Q.E., March 98, this function is obtained by introducing into the cavity 15 (figure 4) a first quarter-wave plate 18, between the mirror 19 and the gain lasing medium 16, a second quarter-wave plate 20 on the other side of the lasing

30   medium, and a polarizer 21 between the plate 20 and the second cavity mirror 22. The two quarter-wave plates 18, 20 and the polarizer 21 make it possible to create two counter-propagating laser beams, of mutually orthogonal circular polarizations (namely a left circular polarization and a right circular polarization). It is also known

that four-beam mixing with these two circularly polarized beams makes it possible to perform the vector phase conjugation, that is to say the depolarization of the fiber is thus corrected.

According to embodiments of the device of the invention, the lasing medium was Nd:YAG then ND:YVO$_4$, the fiber was monomode, then low-loss multimode, and the diffractive component was produced by holography on a photopolymer material.

The advantages of the device of the invention are the following:

- it employs a compact continuous laser source pumped by diodes and serving to generate a conjugate wave by intracavity four-beam mixing;

- the use of a beam splitter produced by a diffractive component makes it possible to operate in the linear response region of the interferometer;

- the device may use a coil of non-polarization-maintaining monomode fiber or multimode fiber; and

- the interferometer is sensitive only to nonreciprocal phase shift effects.

In particular, its operating point is unaffected by the slow variations (due to temperature variations) of the optical path in the fiber coil.